GEORGIA INSTITUTE OF TECHNOLOGY | OFFICE OF CONTRACT ADMINISTRATION

[X] ORIGINAL

PROJECT ADMINISTRATION DATA SHEET

[ ] REVISION NO. ____

Project No. A-2975 DATE: 6/19/81

Project Director: Mr. J. N. Harris ~~XXXXXX~~/Lab EMSL/MRB

Sponsor: The Johns Hopkins University; Applied Physics Laboratory; Laurel, MD 20810

Type Agreement: APL Contract No. 601482-0 under Prime Contract No. N00024-81-C-5301

Award Period: From 5/29/81 To ~~10/31/81~~ ~~11/30/81~~ 10/29/82 (Performance) ---- (Reports)

Sponsor Amount: $17,351 Contracted through:

Cost Sharing: None GTRI/~~XXX~~

Title: Ramjet Nose Inlet Radomes

ADMINISTRATIVE DATA OCA CONTACT Duane Hutchison x 4820

1) Sponsor Technical Contact: R. K. Frazer, Technical Problem Sponsor; The Johns Hopkins University; Applied Physics Laboratory; Johns Hopkins Road; Laurel, Maryland 20810 (301) 953-7110 x 7416

2) Sponsor Admin./Contractual Contact: Mr. K. M. Costello, Contract Representative; The Johns Hopkins University; Applied Physics Laboratory; Johns Hopkins Road; Laurel, Maryland 20810 (301) 953-7100 x 7688

Reports: See Deliverable Schedule Security Classification: Unclassified

Defense Priority Rating: DO-A2 under DMS Reg 1

RESTRICTIONS

See Attached Government Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Government. (DAR 7-203.21) Sept. 1970; however, none authorized/proposed.

COMMENTS:

COPIES TO:

Administrative Coordinator
Research Property Management
Accounting Office
Procurement/EES Supply Services

Research Security Services
~~Reports Coordinator~~ (OCA)
Legal Services (OCA)
Library, Technical Reports

EES Research Public Relations (
Project File (OCA)
Other: ____

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

8R/142 8

Date 2/16/83

Project Title: Ramjet Nose Inlet Radomes

Project No: A-2975

Project Director: J. N. Harris

Sponsor: The Johns Hopkins University; Applied Physics Lab

Effective Termination Date: 10/29/82

Clearance of Accounting Charges: 10/29/82

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________________

Assigned to: EMSL (~~School/~~Laboratory)

COPIES TO:

Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other PD

FORM OCA 10:781

H-211-

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

March 19, 1982

The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20810

Attention: Mr. K. M. Costello

Subject: Final Report, "Nose Inlet Ramjet Radome Fabrication," APL Contract Number 60148, Georgia Tech Project Number A-2975-000, for the Period 29 May 1981 - 31 January 1982.

Gentlemen:

Details of tooling construction and slip-casting techniques used for the first three attempts to slip-cast high purity fused silica radome blanks of the nose inlet ramjet radome shape are described in the Final Report, "Nose Inlet Ramjet Radome Fabrication," by J. N. Harris, prepared for McDonnell Douglas Aerospace Corporation, St. Louis, MO, September 1981.

A. Slip-Casting, Drying and Sintering of Radome Blanks

A combined total of eight casting attempts were made on the McDonnell Douglas and the Johns Hopkins University contracts using the fused silica slip purchased for these programs (Thermo Materials Corporation log number 042781-HPA). Four additional casting attempts were made using an older high purity fused silica slip (Thermo Materials Corporation 030872-2) which previously had been used to cast successfully large, thick-walled radome blanks. Property data for the two slips are summarized in Tables I-III. Particle size distributions are shown in Figures 1 and 2.

Since the McDonnell Douglas contract provided the tooling necessary to slip-cast and machine the radome blanks a verbal agreement was reached between the technical program monitors for McDonnell Douglas (MDAC) and the Johns Hopkins University, Applied Physics Laboratory (JHU-APL) that work would not begin on the JHU-APL radomes until a successful blank was cast and sintered for McDonnell Douglas. After a meeting with McDonnell Douglas and the Applied Physics Laboratory technical monitors in September 1981, the first "successful" blank was considered to be the second casting.

TABLE I

CHEMICAL COMPOSITION OF THERMO MATERIALS
HIGH PURITY FUSED SILICA SLIPS

	042781-HPA Weight Percent	030872-2 Weight Percent
Al_2O_3	0.25	0.30
TiO_2	0.002	0.002
Fe_2O_3	0.008	0.007
MgO	0.008	0.008
CaO	0.007	0.007
CoO	0.001*	---
Cr_2O_3	0.001*	---
SiO_2	99.72	99.67
	Parts Per Million	Parts Per Million
Na	10*	10*
K	10*	10*
Li	10*	10*

*Not detected. The number indicates the minimum limit of detection.

TABLE II

SLIP PROPERTIES FOR THERMO MATERIALS
HIGH PURITY FUSED SILICA SLIPS

	042781-HPA	030872-2
Solid Content (%)	82.70	83.1
pH @ 20^{o} C	4.77	4.8
Viscosity @ 20^{o} C (centipoise)		
@ 6 rpm	100	180
12 rpm	143	155
30 rpm	144	135
60 rpm	138	136
Mean Particle Size (μm)	7.8	7.5

TABLE III

PHYSICAL AND MECHANICAL PROPERTIES OF TEST SPECIMENS

	042781-HPA	030872-2
Elastic Modulus (10^{6} psi)	5.78 $\pm$ 0.18	5.55 $\pm$ 0.06
Modulus of Rupture (10^{3} psi)	6.66 $\pm$ 0.86	4.85 $\pm$ 0.21
Bulk Density (g/cm^{3})	1.958 $\pm$ 0.003	1.955 $\pm$ 0.003
Porosity (%)	10.64 $\pm$ 0.15	10.48 $\pm$ 0.013
Cristobalite (%)	0.3	<1.0

This second casting had a cracked tip, but it was decided that this would not affect the McDonnell Douglas electrical measurements. The first work initiated for Johns Hopkins University was on radome casting number four; however, when it was determined that radome casting number two could not be machined because of a variable wall thickness in the cast part, work and charges reverted to the McDonnell Douglas contract until casting number eight was completed successfully. Casting attempts nine through twelve and the machining of casting nine was accomplished using Johns Hopkins University Applied Physics Laboratory Contract funds. These efforts exhausted the contract funds prior to the impregnation of machined radome blank number nine. Therefore, the work had to be concluded prior to final curing of the impregnated radome blank and with a second radome blank (number 12) ready to be machined.

Since the casting history is of interest to both programs, Table IV summarizes the results of all 12 casting attempts made on the two programs. Six radome casting attempts were made using a 0.5 percent ammonium alginate film on the plaster mold as a mold release, and six casting attempts were made with no mold release film. Two successful castings and four failures occurred with each of the two slips used.

The first successful casting, (number 2), required 18½ hours casting time at 7 psig, and was made with a mold release film. However, this casting did have a crack in the tip area. Three of the final five castings were successful. These were cast without a mold release film under a pressure of 10 psig, for 7¼, 8 and 8 hours, respectively. Two casting attempts ended in failure between the third and fourth successful castings due to slumping and liquefaction of the cast silica wall after removing the internal mandrel and while the part was drying undisturbed in the mold. Figure 3 shows typical failure due to slumping. This phenomena apparently occurred due to a high moisture content within the mold. Prior to the last casting the mold was force dried for nine days.

All radome castings were fired in an electrically resistance heated rotating hearth furnace with the base of the radomes resting on a one inch thick pad of ceramic fiber. Radomes were placed in the furnace at room temperature. The furnace temperature was raised to 1000° C in about 12 hours. The furnace was held at this temperature for four hours then increased to 1196° C over a time period of one and one-half hours. The temperature was held at 1196° C for five and one-quarter hours and then the furnace power shut off. The radomes were allowed to cool in the closed furnace overnight before removal.

B. Machining of the Radome Blanks

The radome blanks were machined by diamond grinding with metal bonded grinding wheels, mounted on an extension arbor of a tool post grinder. Water only was

TABLE IV

RADOME BLANK CASTING RESULTS

Mold/ Casting No's	Mold Release Used?	Casting Date (mo/day)	Casting Time (hr:min)	Observations
1/1	no	7/30	8:30	Failed to completely cast in the area within 1½ inches of the base. Developed vertical cracks running from base toward the tip, 12-14 inches in length during drying.
1/2	yes	8/10	18:30	Cast, dried and sintered; 5¼ hours at 1190^o C. After sintering a circumferential crack was apparent approximately one inch below the end of the tip. Machining was attempted, but wall thickness was found to be variable because the inner mandrel was located too deep in relation to the plaster mold. The wall was too thin in the area of largest curvature to meet wall thickness requirement for the finished radome.
1/3	yes	8/31	18:10	Circumferential crack developed 3 inches below tip on fourth day of drying
1/4	yes	10/6	10:00	Vertical crack 6 inches long and 6 inches from base developed on seventh day of drying.
1/5	yes	10/14	15:45	Radome failed to cast completely at base. Several hours after casting the radome wall liquefied and slumped in two places.

(Continued)

TABLE IV (Continued)

RADOME BLANKS CASTING RESULTS

Mold/ Casting No's	Mold Release Used?	Casting Date (mo/day)	Casting Time (hr:min)	Observations
1/6	yes	10/19	15:50	Radome wall liquefied and slumped after approximately 4 hours of drying. (Slumping of blanks 5 & 6 was attributed to being too wet and possibly having plugged pores)
2/7	yes	11/11	16:00	New mold used and height adjustment made on internal mandrel after discovering variable wall thickness on casting no. 2. Radome cracked between 2 & 4 days after drying began. A vertical crack extended from the base to within 2 inches of the tip.
2/8	no	11/17	7:25	Cast with 030872-2 fused silica slip. Radome dried and sintered 5¼ hours at 1196^{o} C. During machining an apparent flaw was discovered in the wall. This apparent flaw was machined away in removing material from the inner wall. This radome was impregnated and provided to MDAC.
2/9	no	12/16	8:00	Cast with 030872-2 slip. Radome dried and sintered 5¼ hours at 1196^{o} C. Radome fully machined and impregnated.
2/10	no	1/5	8:00	Cast with 030872-2 slip. Small dimples, approximately 1/8 inch deep in several places on inner surface after casting. After one

(Continued)

TABLE IV (Concluded)

RADOME BLANKS CASTING RESULTS

Mold/ Casting No's	Mold Release Used?	Casting Date (mo/day)	Casting Time (hr:min)	Observations
2/10 (Con't)				day of drying there was a small slumped area and a 6 inch vertical crack running from base towards tip.
2/11	no	1/12	8:00	Cast with 030872-2 slip. Circumferential crack near base after removing mandrel.
2/12	no	1/21	8:00	Cast with 042781-HPA slip. Radome dried and sintered 5¼ hours at 1196^{o} C. No apparent flaws in this casting.

used as a coolant. The radomes were machined on a horizontal lathe fitted with a variable speed motor so that surface speed of the work piece remained constant regardless of the diameter at the point of grinding. The grinder was mounted on the tool post and the cross feed of the lathe disconnected. A pneumatic cylinder was used to drive the crossfeed and a follower wheel mounted on it into contact with the template defining the radome shape. This was the same template used to machine the master model and internal mandrel used in casting the radomes and is shown in Figure 4. The inside of the radome blank was machined first. For this operation the radome was held in a vacuum chuck as shown in Figure 5. Details of the vacuum chuck are shown in the McDonnell Douglas Final Report. Although the use of vacuum to hold the radome for machining is normal procedure, it was found in machining the McDonnell Douglas blank that the vacuum force was sufficient to cause the radome to go out-of-round during machining. After machining and taking the radome out of the chuck it was found to be elliptical in shape. This problem was solved by using polyurethane foam to form an adhesive bond at the line of contact between the chuck and the radome exterior surface; no vacuum was used. This foamed bond line can be seen in Figure 5. The initial step in machining was to cut off the base of the radome so that it was square and could be used as an indexing point to establish the template position. The inner surface was then machined with a two-inch diameter grinding wheel by successive passes removing approximately 0.020 inch of material on each pass until the inner diameter approached the desired machined diameter. The inside tip area where the diameter was less than two inches was machined with a ½ inch diameter diamond button. The final cuts were made by removing approximately 0.005 inch of material per pass.

After achieving the correct internal diameter the radome and chuck were removed from the lathe and the vacuum mandrel, shown in detail in the McDonnell Douglas report was set-up. The set-up for external machining is shown in Figure 6. The template position was reversed and the radome base used as an indexing point for locating the template position. The exterior surface was machined in the same manner as the interior except a shoulder was left at the base to accommodate the McDonnell Douglas mounting ring. As the desired wall thickness was approached it was necessary to remove the radome from the lathe and measure the wall thickness mechanically as shown in Figure 7. Removal and replacement of the radome on the vacuum mandrel was a time consuming operation, but was necessary with the equipment available for measuring wall thickness.

Upon completion of machining of the walls of the radome and before removing the radome from the vacuum mandrel, the radome tip was cut off and contoured to accept a machined stainless steel tip as shown in Figure 8. A hole was drilled through the radome tip so that the metal tip could be spring mounted to allow for expansion during heating.

C. Resin Impregnation of the Machined Radome

The stainless steel tip was removed and the radome thoroughly dried at 130^{0} C to remove all moisture from the machining operation. The hole in the tip of the radome was plugged with a neoprene washer held in position with a nut and bolt. The radome was placed in a base-up position in a large plastic bag in which a small amount of toluene had previously been poured. The radome was then filled with General Electric Silicone Resin 182. The plastic bag was then tightly closed around the radome. Closing of the bag and the toluene outside the radome is necessary to establish a partial pressure of toluene in the area surrounding the radome. Otherwise the toluene diluent in the SR 182 resin will rapidly evaporate from the outer surface causing an increase in the viscosity of the resin and hence, failure of the resin to penetrate completely through the radome.

The exterior surface was then periodically inspected for wetness on the outer surface as an indication that the resin had completely penetrated the radome. For radome number nine seven days were required for the resin to impregnate completely through the radome wall. The excess resin was drained from the interior of the radome and the radome readied for cure in the rotating hearth furnace used to fire the radome blanks.

The curing procedure is to raise the temperature at a rate of one degree Celsius per minute to a temperature of 250° C, then hold at temperature for four hours. The furnace is cut off and the cured radome allowed to cool in the furnace. After curing the exterior and interior of the radome requires a considerable amount of sanding to remove bumps and high spots in the resin coating. Once this is accomplished the metal tip can be reinstalled and the radome is complete.

D. Discussion

The Georgia Institute of Technology has had a considerable amount of experience in slip-casting various radome shapes ranging in size from two inches in base diameter and eight inches tall to 24 inches in base diameter and 48 inches tall. However, all the previous experience has been with simple shapes such as cones, ogives, Von Karmann and 3/4 power series. The compound curves and large radius of curvature sections of the nose inlet ramjet radome shape created problems not previously experienced in slip-casting high purity fused silica radomes. For example, with cones and ogive radome shapes the normal drying procedure for the radome is to dry it tip down in the mold. As the radome dries and shrinks it is cradled and fully supported by the mold wall. This was not true with the nose inlet ramjet radome shape, as this shape shrank in the mold the large curvature section could not "fall" deeper in the mold. As a result the entire tip section was hanging freely in the mold, and undoubtedly created some stresses in the weak casting. The second difference was the large base diameter (18.5 inches as cast and sintered). Except for the 24 inch base diameter tangent ogive radome 48 inches in length which was drain cast, the nose inlet ramjet radome shape represents the largest base diameter radome that has been slip-cast at Georgia Tech. It is the largest diameter radome that has been precision slip-cast. Also, the large diameter prohibited the use of a vacuum holding device for machining as described above. This problem was anticipated for the nose inlet ramjet radome shape with a wall thickness on the order of 0.22 inch, but was not expected to be a problem with a 0.45 inch wall.

Because of the problems described above, development costs were greater than anticipated and it was not possible to complete a radome and provide it to Johns Hopkins University, Applied Physics Laboratory within the allotted research budget on this cost reimbursement contract. However, one radome was completed except for curing the resin coating, sanding to a smooth finish and reinstalling the stainless steel nose tip. A perfect second casting was achieved and would only require sufficient funds for machining and impregnating to provide a second radome.

Respectfully submitted,

Joe N. Harris
Project Director

jw

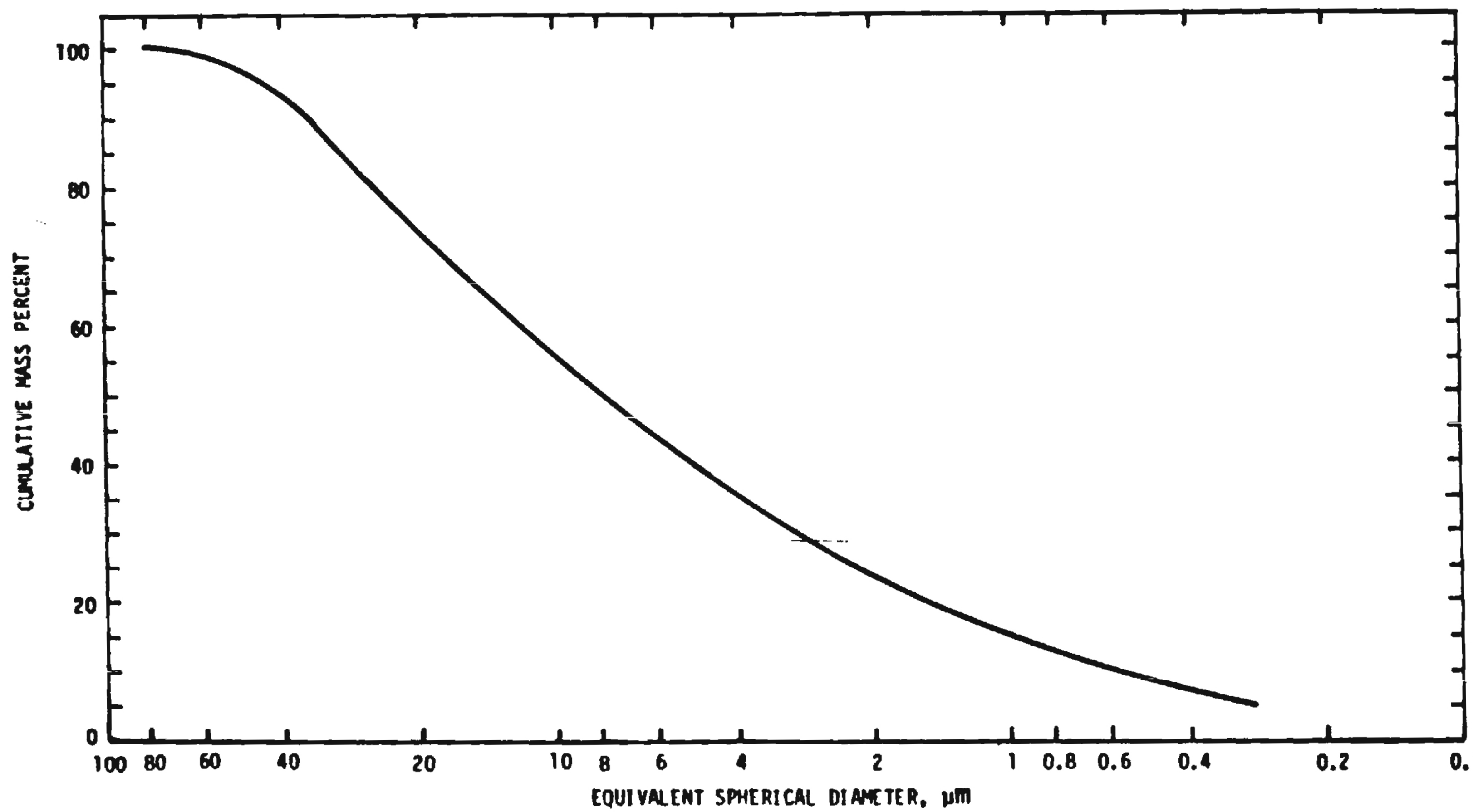


Figure 1. Particle Size Distribution of High Purity Fused Silica Slip 042781-HPA.

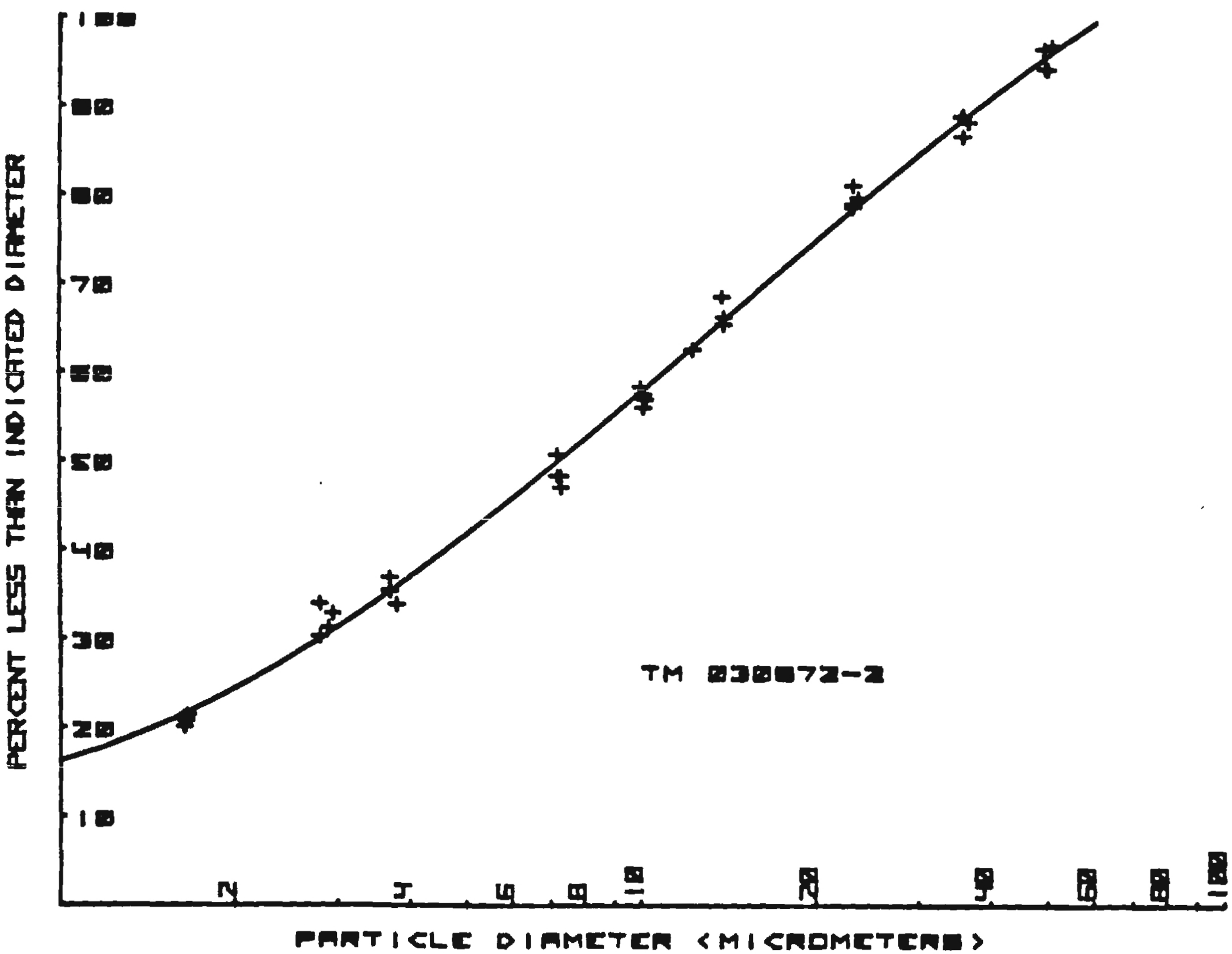


Figure 2. Particle Size Distribution of Thermo Material's 030872-2 High Purity Fused Silica Slip.

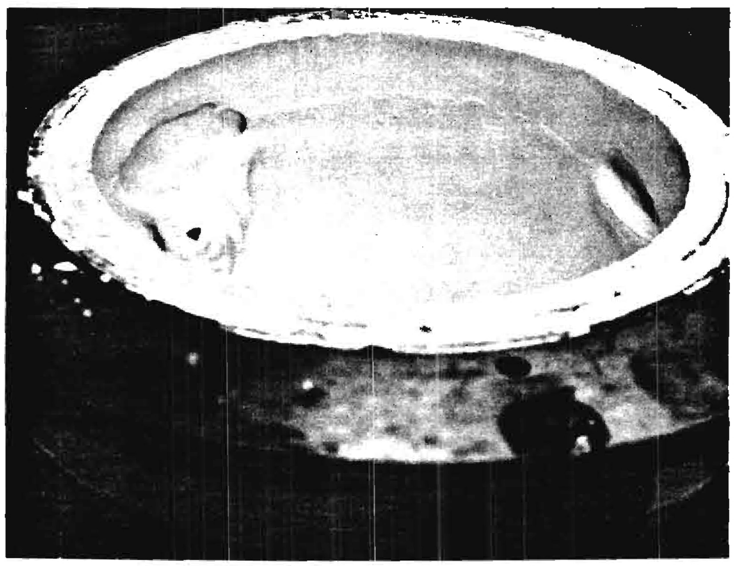


Figure 3. Slumped Areas in Radome Casting Number Five

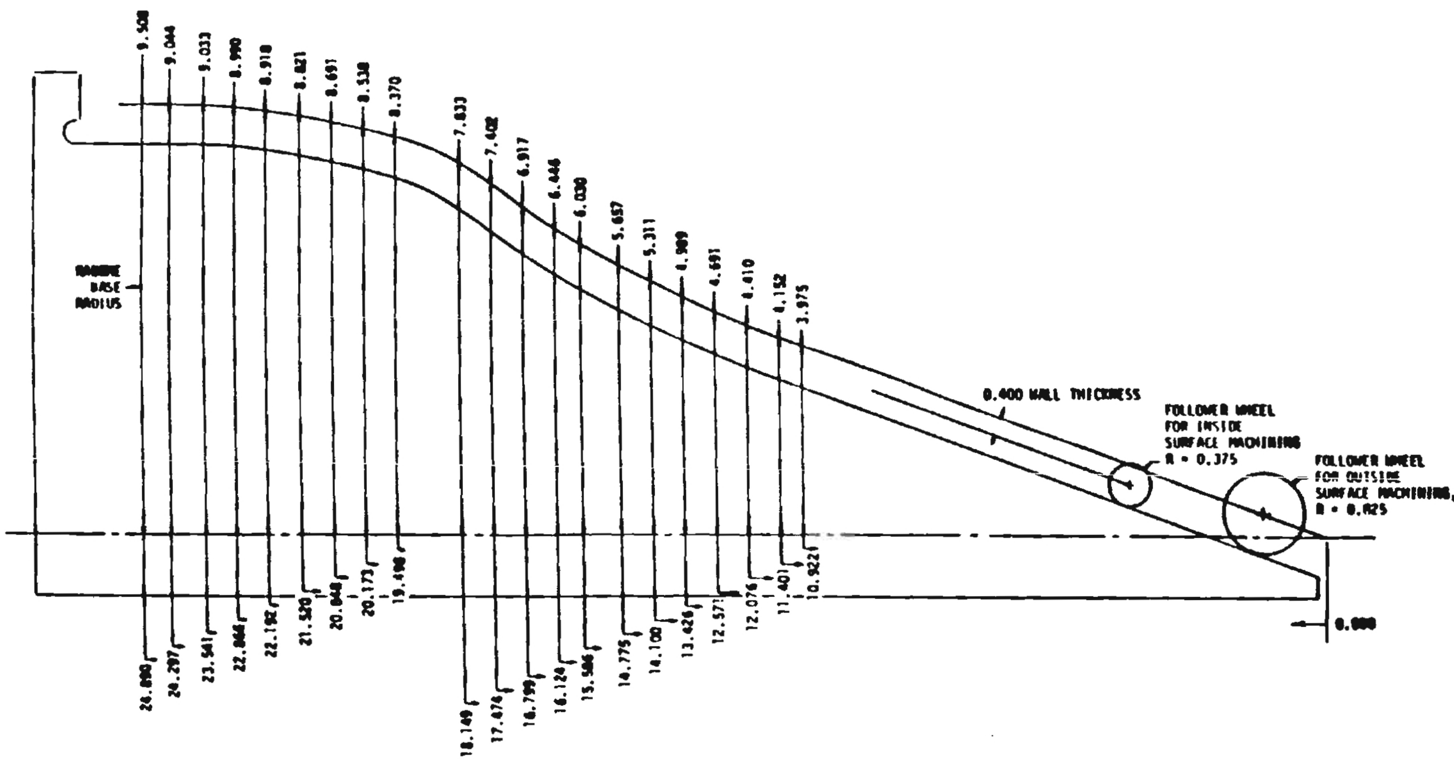


Figure 4. Template Shape Showing Location and Points Traced by Follower Wheels.

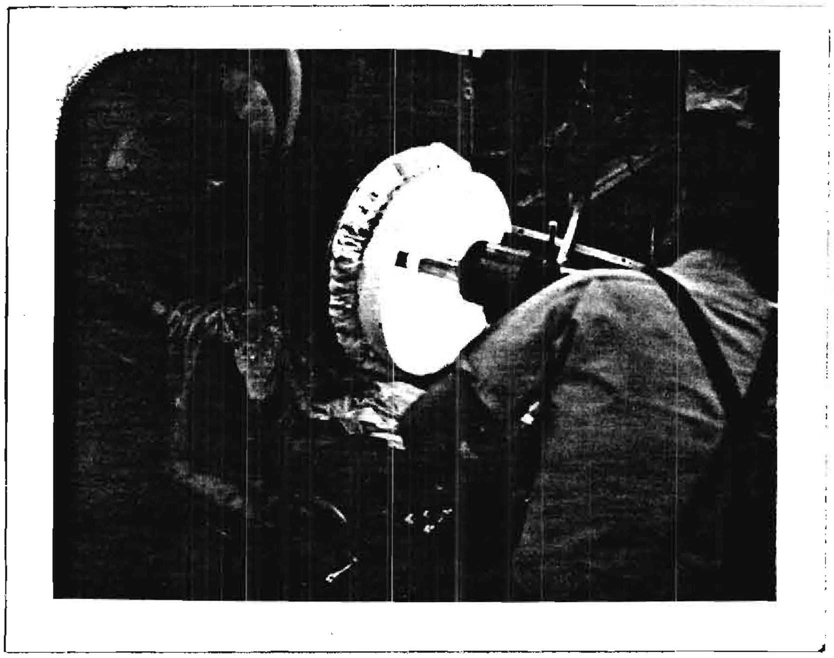


Figure 5. Lathe Setup for Internal Machining Showing Vacuum Chuck and Polyurethane Foam Bond Line at Radome-Chuck Interface

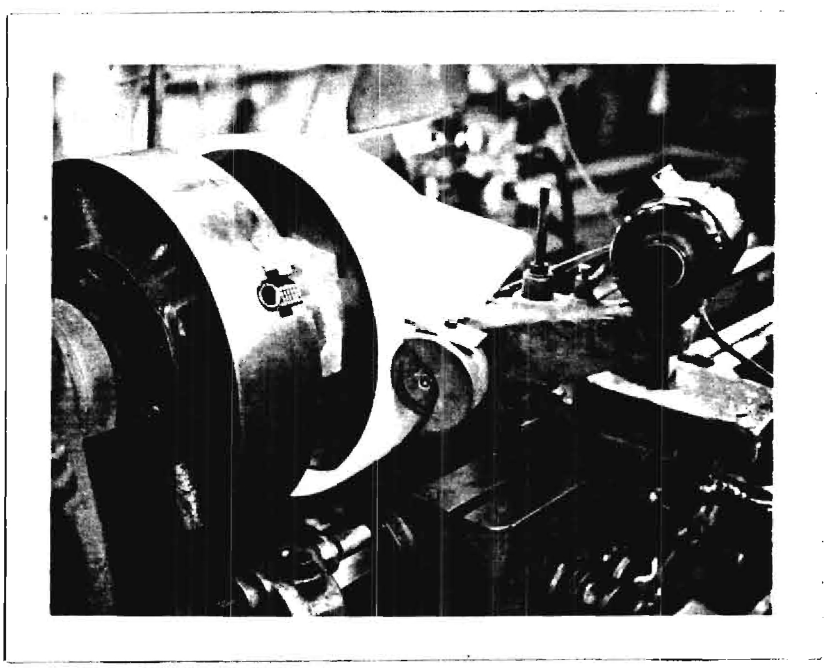
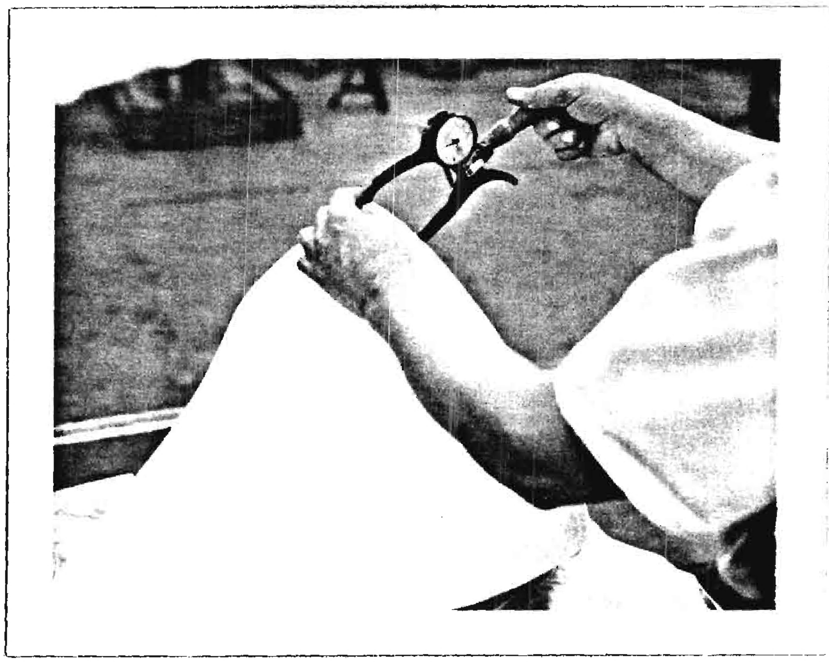


Figure 6. Radome Setup on Vacuum Mandrel for External Machining



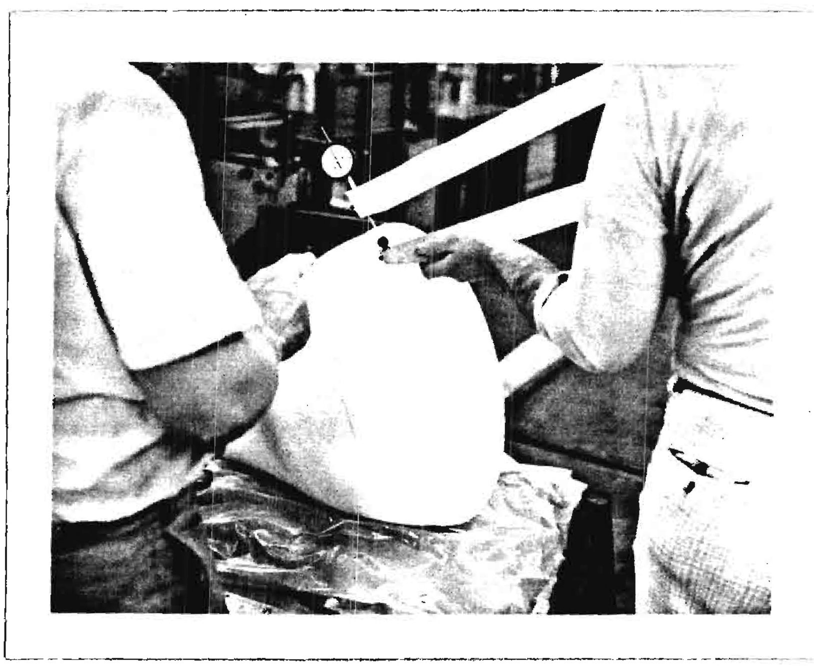


Figure 7. Mechanical Measurements of Radome Wall Thickness

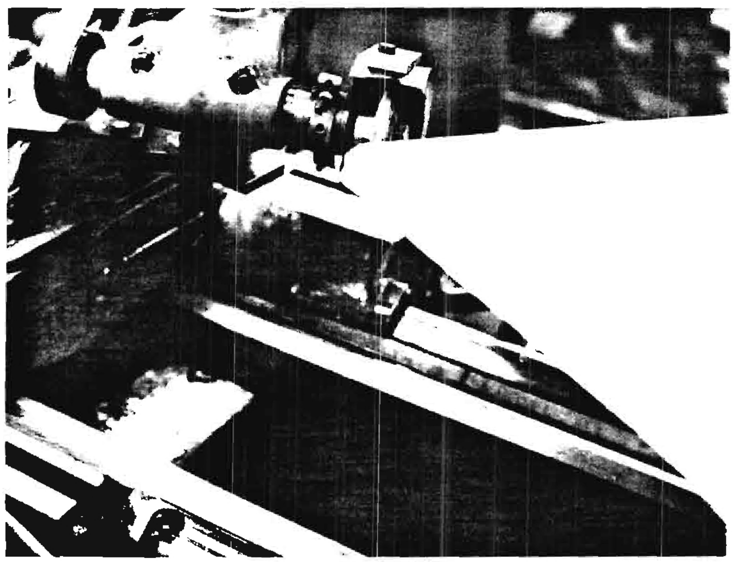


Figure 8. Machining of Radome Tip Area

A-2975

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

November 11, 1982

The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20810

Attention: Mr. K. M. Costello

Subject: Addendum to Final Report, "Nose Inlet Ramjet Radome Fabrication," APL Contract No. 60148, Mod 5, Georgia Tech Project Number A-2975-000 for the Period 1 September - 29 October 1982

Gentlemen:

The purpose of this addendum is to describe the procedures used in machining the outer surface of an additional high purity fused silica radome blank (casting 2-12, Table IV of Final Letter Report, dated March 19, 1982) to the shape and wall thickness shown in APL drawing number 24-19125, dated 4 August 1982.

The McDonnell-Douglas radome shape was mounted on a three inch diameter shaft using three, 3/4-inch thick plywood discs of varying diameters to hold the radome concentrically on the shaft. The edges of the discs were machined to match the radome wall taper at the point of contact between the discs and the radome wall. The first disc was pushed forward on the shaft until it made contact with the inside diameter of the radome blank approximately one inch behind the solidly cast tip area of the blank. The second ring made contact with the blank approximately one inch forward of the final desired length of the radome. A two-component foam-in-place styrofoam was then used to fill a four-inch section behind the second ring. This foam extended past the station at which the base was to be parted from the front end of the radome shape. The styrofoam served two purposes: (1) it secured the radome blank to the mandrel during machining, and (2) it held the rear section during and after cut-off to prevent any movement which might bind the cut-off wheel. The third disc was placed approximately one-inch inside the radome blank base to hold the rear portion securely when it was cut free from the forward area.

The radome was machined on the outer surface using a two inch diameter by 1/8 inch thick metal bonded diamond grinding wheel mounted in a tool post grinder. The first operation was to cut the rear portion of the radome off at a point that left approximately one inch of excess length at the base of the forward section. The shaft was taken out of the lathe and the rear section removed. A plug was cut out of the styrofoam and the second plywood disc so that wall thickness measurements could be made with a caliper type device without removing the radome and the concentric shaft from the lathe.

The excess material was ground from the exterior surface by making continuous cutting passes (0.02 inch/pass) with the lathe cross feed following a template corresponding to the desired 20^o and 27^o angles. After reaching the desired wall thickness the tip area was cut-off and contoured to accept a machined stainless steel tip as shown in Figure 8 of the final report. A 1/4-inch diameter hole was drilled through the ceramic radome tip so that the metal tip could be spring mounted to allow for differential expansion between the metal and ceramic during aerodynamic heating.

The correct radome length was established by temporarily installing the metal tip and measuring from the apex of the tip back 14.0 inches. The excess base length was then cut off and the machining completed by cutting a cylindrical section 0.24 inch in length forward from the base of the radome.

After completion of the machining operation the styrofoam was cut away and the radome placed in a kiln at 650^o C for one hour to oxidize the styrofoam residue and any other organic materials that might have contaminated the radome surface during or after machining. After cooling the stainless steel nose tip was reinstalled. The radome was packaged and shipped to APL to the attention of Mr. Kelly Frazer.

Respectfully submitted,

Joe N. Harris
Project Director

jw